

Two types of paleoecologic products are particularly useful, namely (1) paleobathymetric well logs, and (2) occurrence charts on which fossils found in a well are arranged in sequence and groups according to their paleoecologic significance.

The ultimate objective is to utilize all the interpreted paleontologic data in the most effective manner for maximum contribution to the exploration program. The logs are synthesized to produce paleobathymetric maps, cross sections, and other displays, which support the exploration effort in numerous ways, such as (1) reconstructing geologic history, (2) recognizing eustatic sea-level changes and evaluating their influence on reservoir sand distribution patterns, (3) enhancing well correlations, and (4) defining depositional trends which are favorable for hydrocarbon accumulation.

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Sedimentary Aspects of Organic Material in Green River Shale

Characteristics of the organic material in Green River Formation shale suggest that this material was derived mainly from algae that grew in Eocene lakes. The basin depressions were formed by the uplifting of the Rocky Mountains. Large quantities of soluble salts flowed into these basins from the mountain streams, increasing the salinity of the lakes until they became chemically stratified. In the upper, relatively freshwater section of the lakes, abundant quantities of microscopic algae and other biota grew. The lower section of the lakes became highly reducing and stagnant because of lack of seasonal oxidative turnovers, thus providing ideal conditions for the accumulation and preservation of the organic debris.

Precipitation of mineral carbonates and silicates from the highly saline waters provided most of the minerals that were co-deposited with the organic matter. The characteristics of the lake water varied considerably and significantly effected the composition of both the inorganic and organic constituents of the Green River shale.

Sixty to seventy-five samples from each of three basins of the Green River Formation were analyzed for changes in the organic constituents. Considerable variations in the organic components of the soluble bitumens and of the insoluble kerogens were evident. Some of these variations appeared to be related to depth of burial and some to source material or the environment of the lake water. Compositional differences were related to lithologic differences in the sediments of the three basins.

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Castillo Gas Field, Spain

Spain's first hydrocarbon discovery, the No. 1 Castillo drilled by CIEPSA near the northern city of Vitoria, was completed as a gas well in 1961 and continues to produce a small but locally important amount of gas from a thick fractured marl. The field is not significant

economically but does provide nearby industry with needed fuel and gives information on the behavior of a type of reservoir which will become more important in the future as demand and prices increase.

Located on the south flank of the Cantabrian trough, the reservoir section of Turonian and Cenomanian age is between 2,000 and 3,000 m deep on a large anticlinal structure formed during Alpine orogenic events. More critical than structural closure are the various fracture systems which create both reservoir volume and permeability in the 1,000-m column of marls, thin limestones, and minor quartzitic sandstones. Effective primary porosity is negligible.

The field has produced over 1.2 Bcf since 1963 out of an estimated ultimate reserve of 2 Bcf. A variety of drilling, completion, and stimulation techniques have been used in attempting to extend production without marked success; however, higher prices for gas may result in a reevaluation of these methods. It is anticipated that modest reserves such as these will be needed in the future.

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Central Mediterranean Thrust Belts

The Alps and Apennines contain major thrust-associated hydrocarbon reserves and unexplored deep prospects in Mesozoic platform carbonate rocks and in Tertiary foredeep fill. The belts contain an S-curved, originally west-facing plate stack composed of the European craton, a sandwiched ophiolite belt, and the Africa-derived Adria plate, in turn overridden by the Tethyan Dinarides. The Vienna basin and the Calc-Alpine contain hydrocarbon reserves and prospects in upper-plate carbonate rocks, in overridden foredeep fill (Molasse) and shelf (Helveticum). Swiss and French lower-plate prospects depend on depth to foreland basement and on structure of allochthonous massifs. On the back side of the orogene, thrusts antithetic to collision loop around the Po basin (with its major oil and gas deposits), involving reworked arc-trench sediments and shelf carbonate rocks. In the southern and central Apennines, the detached shelf unit is exposed. In the northern Apennines, it is thrustured and covered beneath resediments. Refraction seismic data indicate the limits of the thrust configuration. In Calabria and Sicily, antithetic thrusting becomes predominant, outlining a subduction flip with a deep Benioff zone, a volcanic-island arc, and prospects on south-facing shelf carbonate thrust sheets beneath chaotic trench fill. In the Dinarides, surface structure, dimensions, some reflection seismic data, and crustal data suggest a classic thrust belt involving similarly prospective sediments.

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Appalachian Thrust Belt Between Trenton, Georgia, and Tuscaloosa, Alabama

Of the 260 km of late Paleozoic westward transport inferred for the Blue Ridge thrust mass, 70 to 100 km affect the Valley and Ridge thrust belt. Transport is

powered by subductive closing of the Ural-Proto-Atlantic ocean system, but distinct styles and kinematic sequences are imposed through gravity spreading by synorogenic topography, and by 1.5 to 4.5 km of foreland subsidence succeeding 2.5 to 6 km of cratonic shelf subsidence. Traditional exploration prospects are surface folds and frontal thrusts within a Silurian to Mississippian clastic wedge thinning southward from 6.5 to 0.5 km. Future prospects are in lower Paleozoic carbonate rocks involved in subthrust structures and, perhaps, in rift fill below the regional decollement. Risk is related to porosity distribution and to surface-water invasion. Overthrust styles include: detached folds and bed-parallel decollements; sled-runner thrusts, folded-fault structures, and polyphase thrusts; and fold-discordant thrust sheets. Some styles predominate regionally: folded-fault structures in the north and the south, imbricate stacks in the middle, and fold-discordant thrusts in the south. There is no hard evidence of eastward migration of thrusting. Kinematic sequences suggest that a frontal subbelt of detached folds or decollement always was located west of a subbelt of thrust imbrication. Basement subsidence, thrust pileup, erosion, and foredeep sedimentation caused the subbelts to shift position and width, thereby generating kinematic sequences essential for the definition of prospects.

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Zenith Field—Significant Dakota (Muddy) "D" Sandstone Discovery, Adams County, Colorado (Secs. 17-20, T3S, R62W)

Zenith field is located on the moderately-dipping, eastern flank of the Denver-Julesburg basin, approximately 43.4 km east of Denver. The field was discovered in March 1979, with the completion of Empire Drilling Company 1 Hilton for 1,285 bbl of oil per day and 750 Mcf of gas per day from the Lower Cretaceous (Muddy) "D" sandstone from 2,222 to 2,234 m. Development drilling by Empire, Champlin Petroleum Inc., and Amoco Production Co. has increased the number of producing wells in the field to five "D" sandstone wells and one Muddy "J" sandstone well. The initial potentials of the additional wells range from 50 to 500 bbl of oil per day with 1,000 Mcf of gas per day. Cumulative production for the field to November 1, 1979, was estimated at 96 thousand bbl of oil and 64 MMcf of gas. Several other wells are in the process of being drilled and completed. Six wells in the field have been plugged and abandoned.

The "D" sandstone throughout the D-J basin is developed as marine-bar and distributary channel sandstones, and hydrocarbon accumulations are found primarily in stratigraphic traps. Zenith field is part of an east-west trending distributary channel which is also productive at Strasburg field, 3.2 km to the east, and Bennett field, 5.6 km to the west. The channel averages less than 1.6 km in width. The productive limits of all three fields are controlled by the pinch-out of porosity and permeability associated with facies changes within the channel. At least three distinct facies can be identified from well logs in Zenith field.

The "D" sandstone of Zenith field is predominantly fine grained, poorly sorted, and very shaly. The sandstone ranges in thickness from less than 6 m to greater than 15 m. The "D" sandstone thickness in producing wells is usually greater than 12 m. The average porosity and permeability in the "D" sandstone are low.

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Oil-to-Source Correlation—Pineview Field, Overthrust Belt, Utah

The Pineview field, discovered in 1975, started the recent expansion of exploration in the Overthrust belt and produces mainly from the Jurassic Nugget and Twin Creek formations. Mass spectra, gas chromatographs, and carbon isotopes show that oils from the two formations are geochemically similar, which suggests that they were generated in the same or similar source rock. Source evaluation data indicate that Cretaceous shales and the Phosphoria Formation are the best potential source rocks in this part of the Overthrust belt. An oil-to-source correlation shows that the Pineview oils are related to the Cretaceous source rocks rather than the Phosphoria. A Cretaceous source is geologically reasonable at Pineview because Cretaceous shales of the subthrust section underlie the Jurassic reservoirs. The geochemistry of the different Cretaceous formations is quite similar, probably because of their generally similar depositional environments. Therefore, it is not possible to determine which Cretaceous formation is actually the source of the Pineview oils.

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Facies Control on Bitumen Saturation, Peace River Oil Sands Deposit, Alberta, Canada

In the Peace River oil sands deposit an estimated 75 billion bbl of heavy oil are trapped at the updip pinch-out of the Lower Cretaceous Bluesky and Gething Formations, at depths of 1,500 to 2,500 ft (457 to 762 m). The principal oil-saturated sand body occurs near the updip edge of the reservoir and averages 80 to 100 ft (24 to 31 m) in thickness. Downdip, the Gething Formation thickens to over 250 ft (76 m) but becomes mainly shale with a few thin sands. Throughout the area it is capped by thin marine sands of the Bluesky Formation. Based upon palynology and sedimentary structures, this sequence grades upward from continental through brackish to marine.

Sedimentary structures of a channel sequence are clearly displayed in the main sand body. From bottom to top the sequence is: a channel lag deposit containing abundant disoriented detrital carbonaceous fragments, plane-bedded or structureless sand, large scale cross-bedded sand, smaller scale cross-bedded sand, and structureless or bioturbated sand containing abundant glauconite. Laterally this sequence commonly grades into thinly interbedded oil-saturated sand and shale.

Reservoir properties vary between the facies. The channel lag deposits have coarser grain size, less inter-